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[54] **HIGH CAPACITY CRYOPUMP**

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[51] **Int. Cl.**^{7} **B01D 8/00**

[52] **U.S. Cl.** **62/55.5**

[58] **Field of Search** 62/55.5; 55/DIG. 15; 417/901

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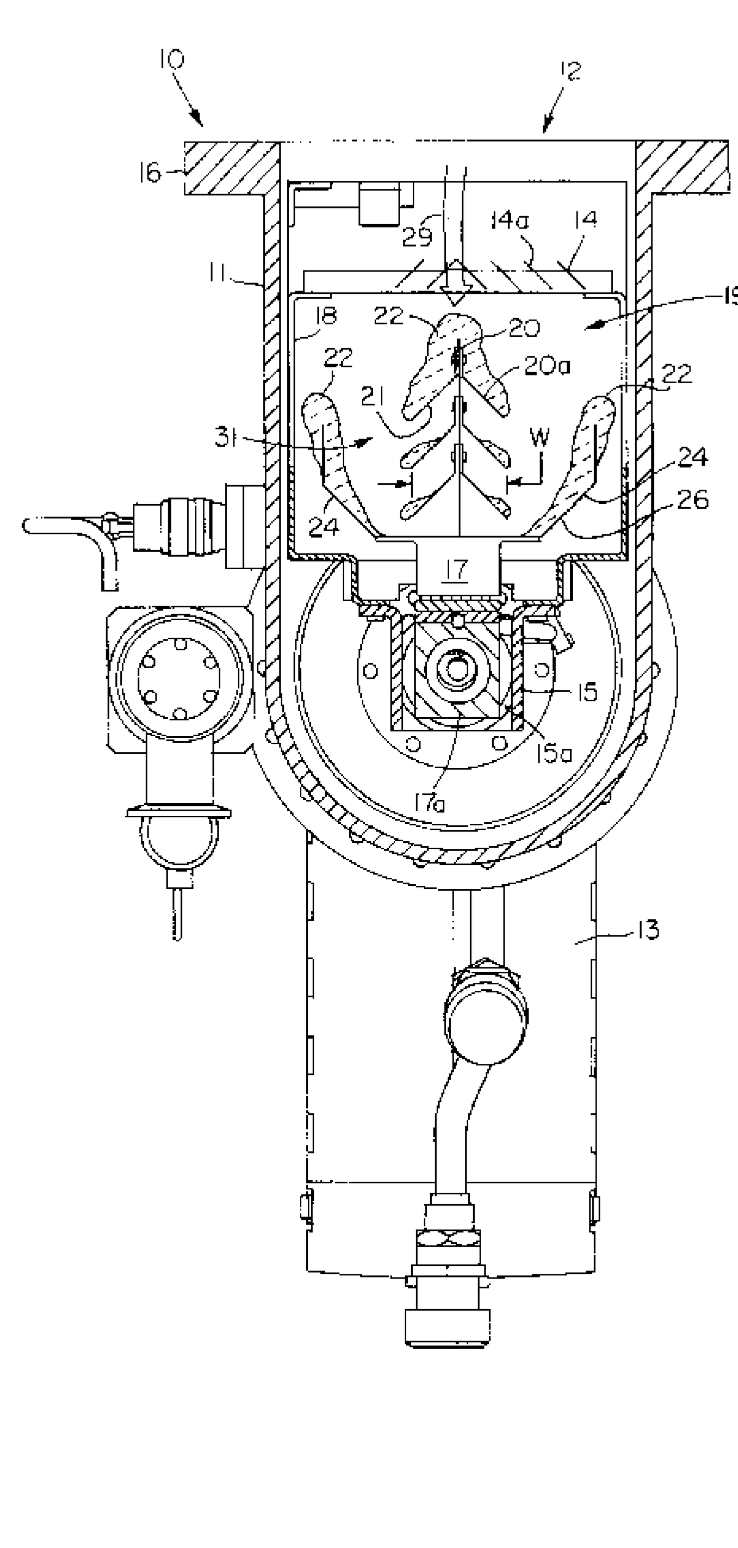
[57] **ABSTRACT**

A cryopump including a radiation shield having an interior surrounded by at least one wall. The radiation shield has an opening through which gases are cryopumped into the interior. A frontal cryopanel array is positioned near the opening for condensing high boiling point gases. The radiation shield and frontal cryopanel array are cooled to a first temperature. First primary cryopanel surfaces extend near the wall within the interior of the radiation shield and are cooled to a second temperature below the first temperature for condensing low boiling point gases near the wall while leaving a central gas flow pathway from the opening past the first primary cryopanel surfaces. Second primary cryopanel surfaces cooled to about the second temperature are positioned within the interior of the radiation shield and include adsorbent for adsorbing very low boiling point gases. The first primary cryopanel surfaces limit the amount of low boiling point gases condensing on the second primary cryopanel surfaces while leaving open the central gas flow pathway to the second primary cryopanel surfaces.

28 Claims, 5 Drawing Sheets



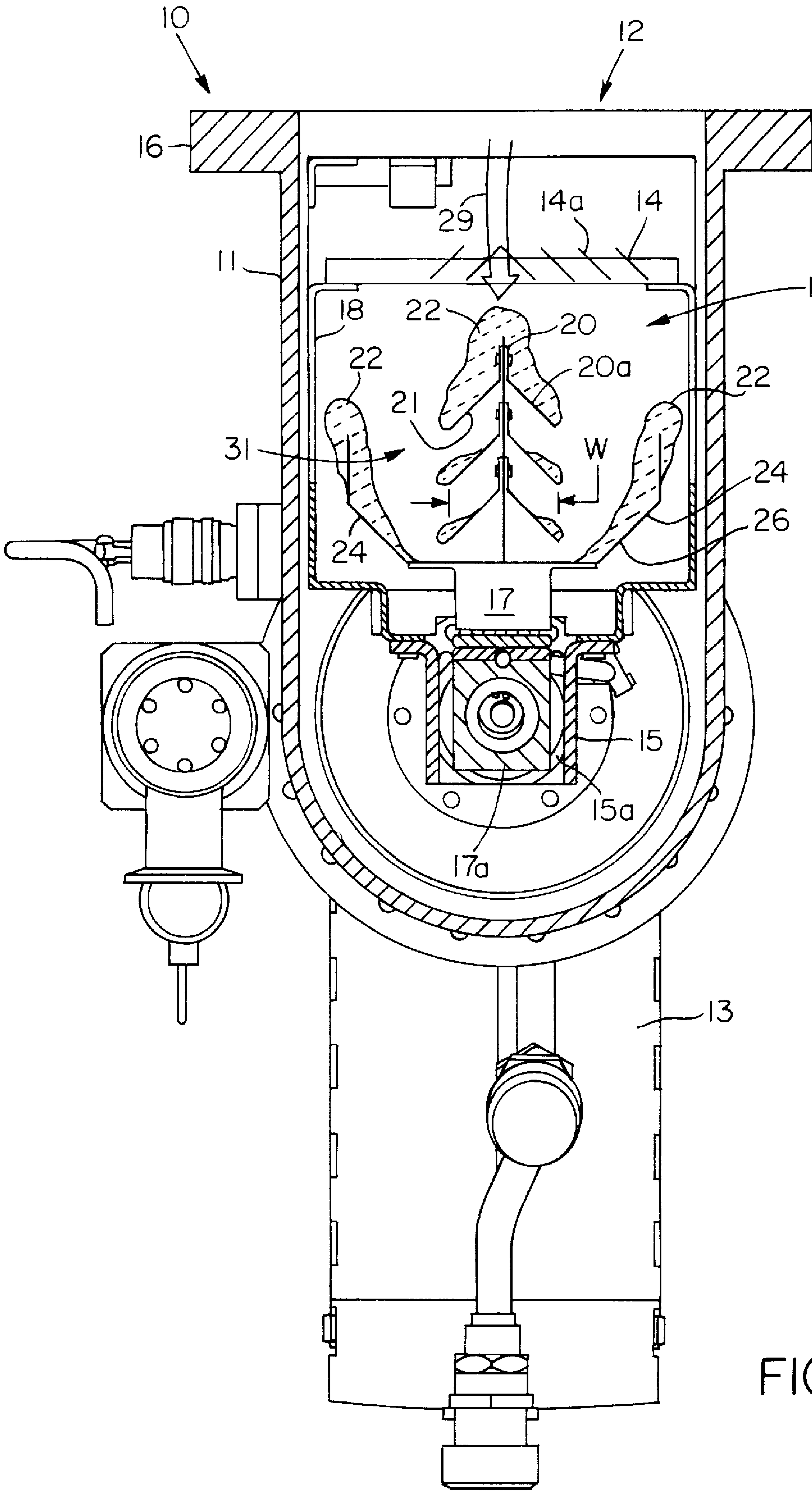

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FIG. 1

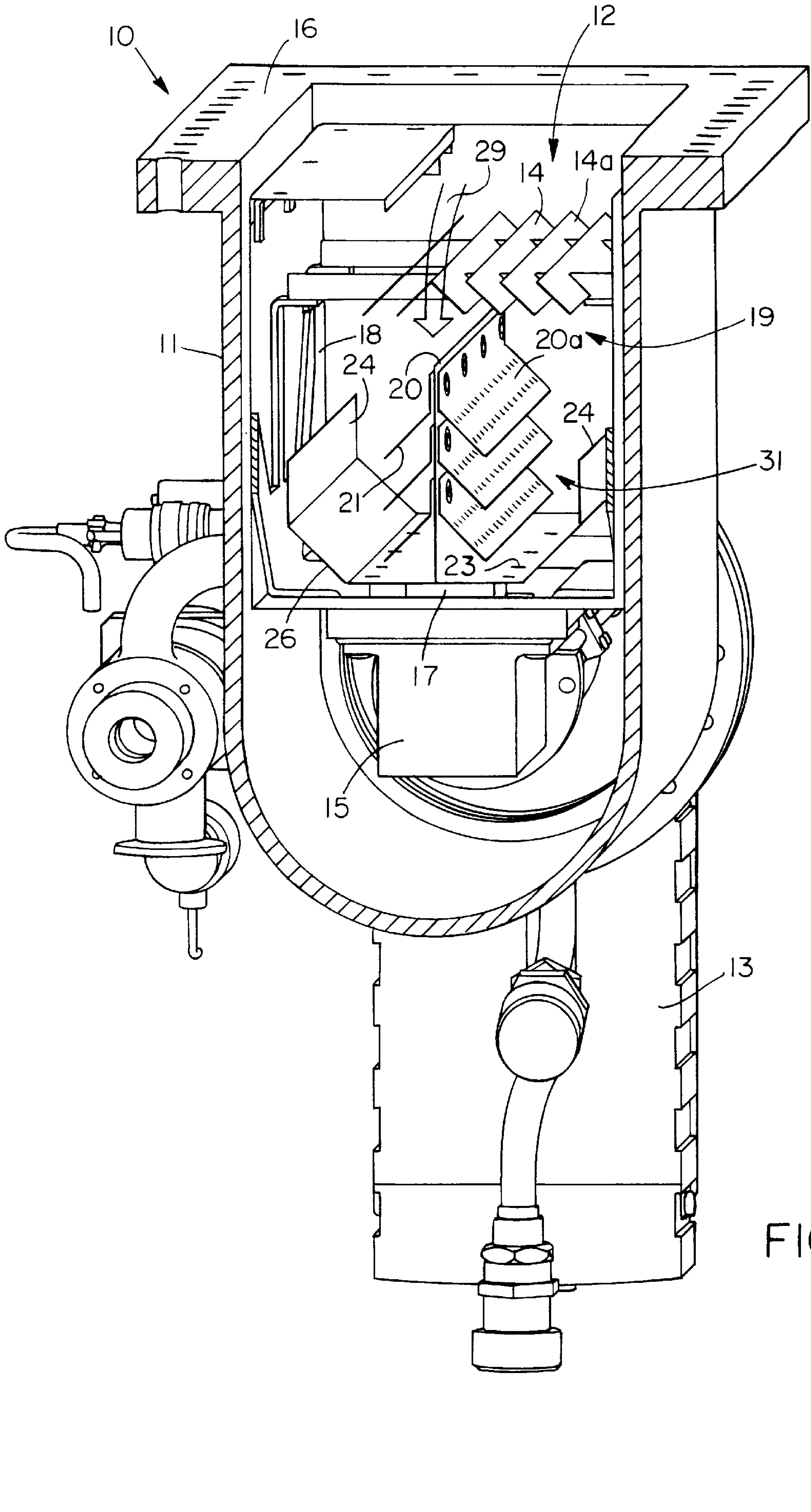


FIG. 2

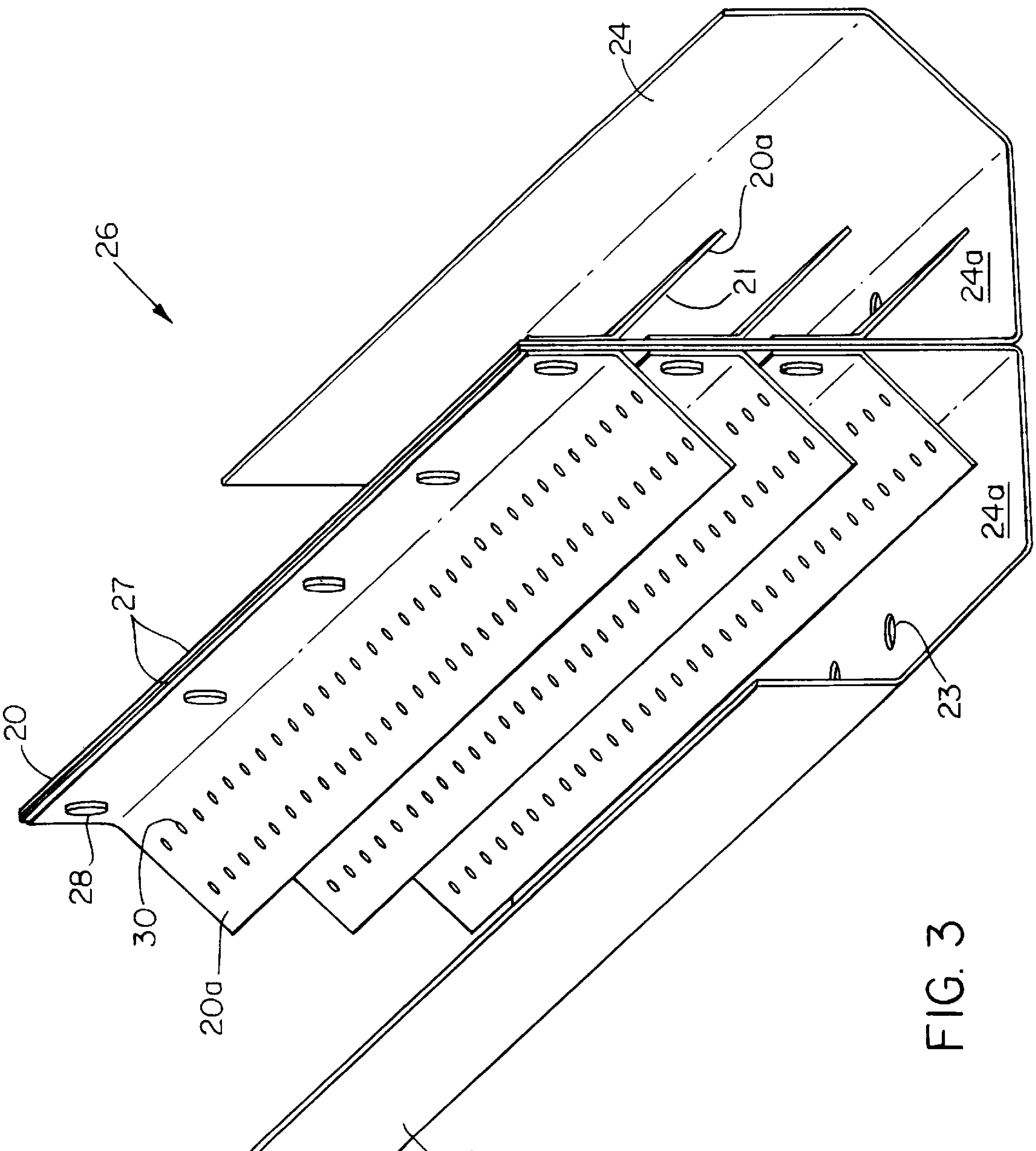
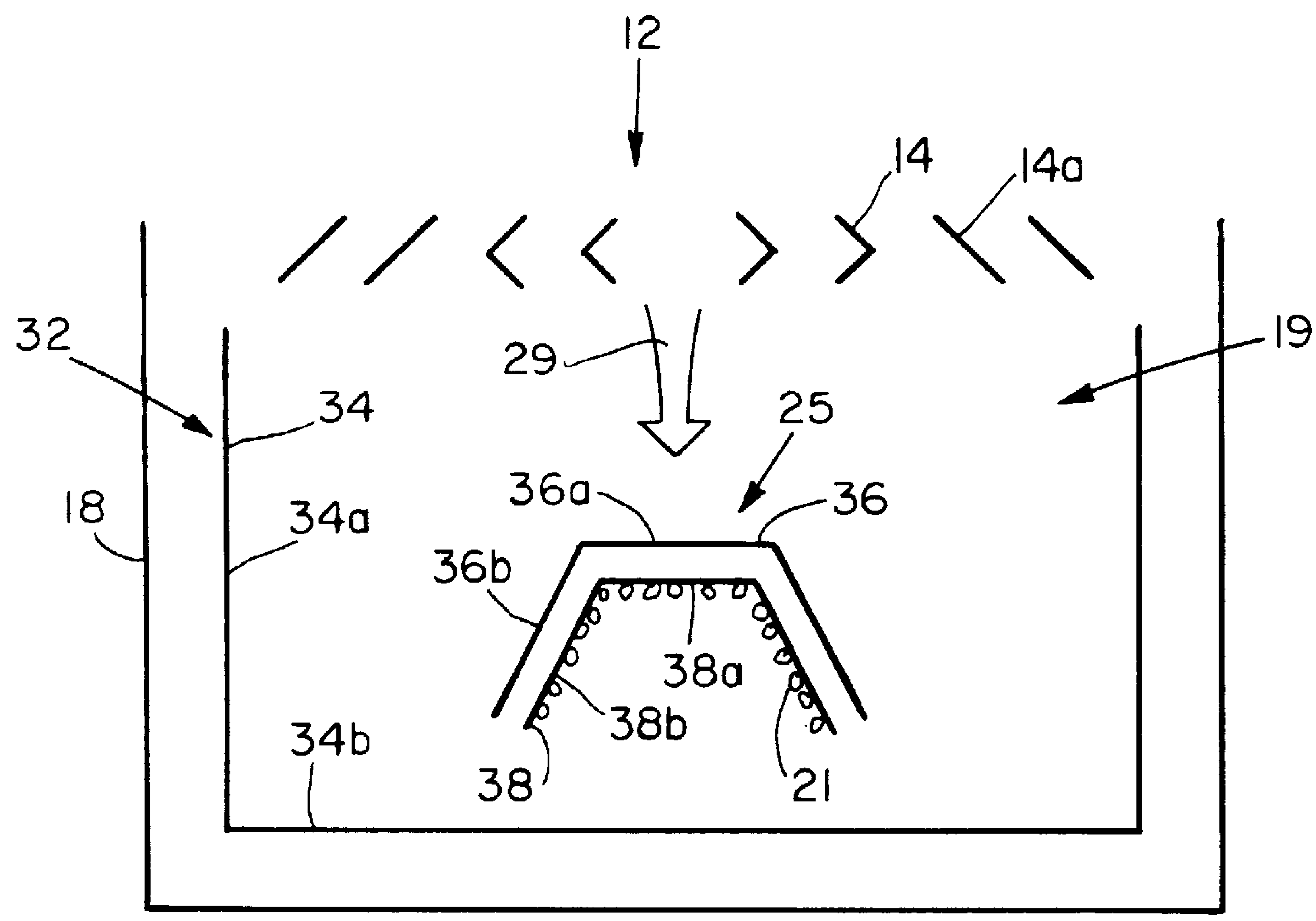


FIG. 3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14
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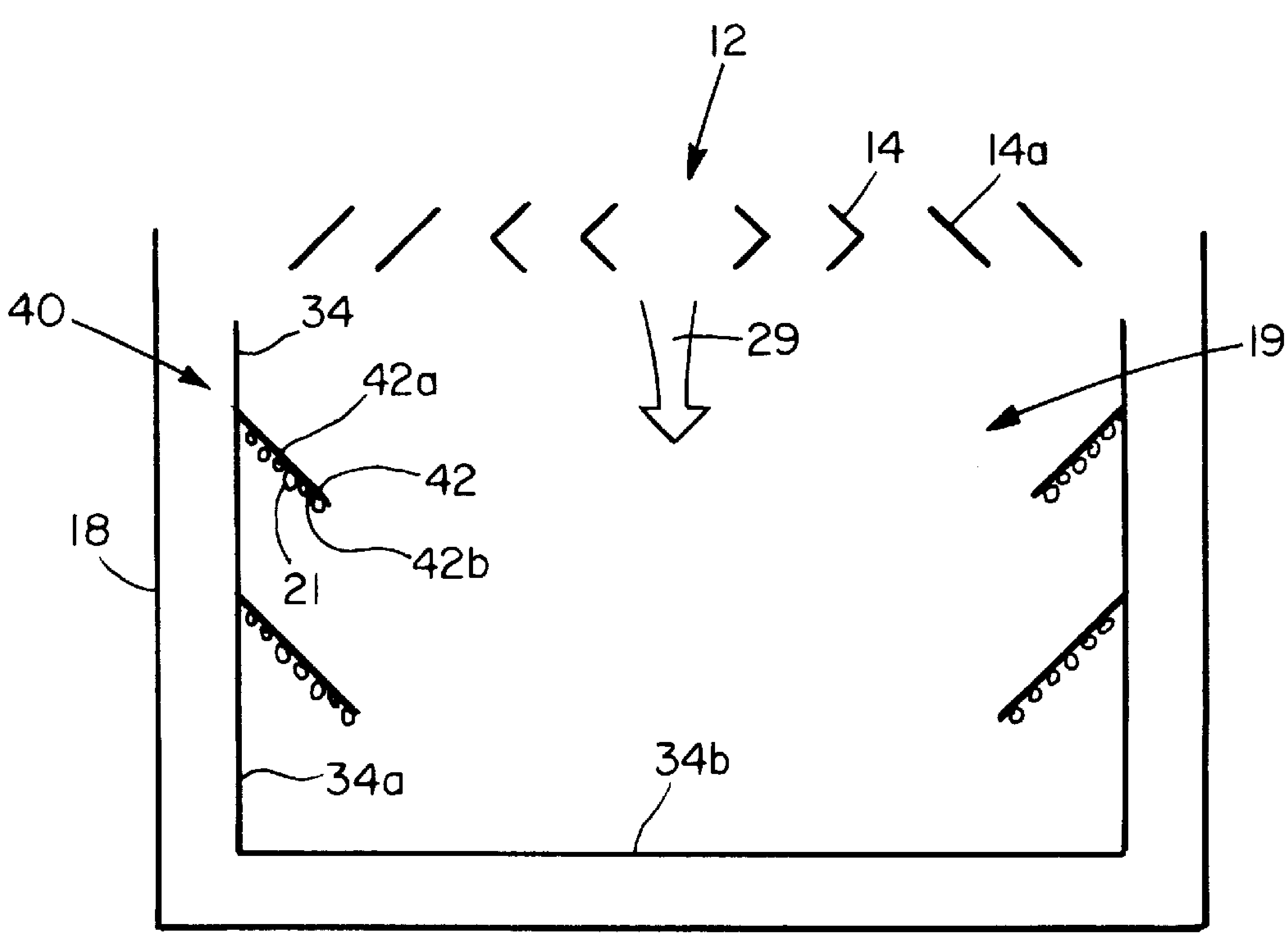
34b
38
21

FIG. 4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42
18
21
42b
34a
34b

FIG. 5

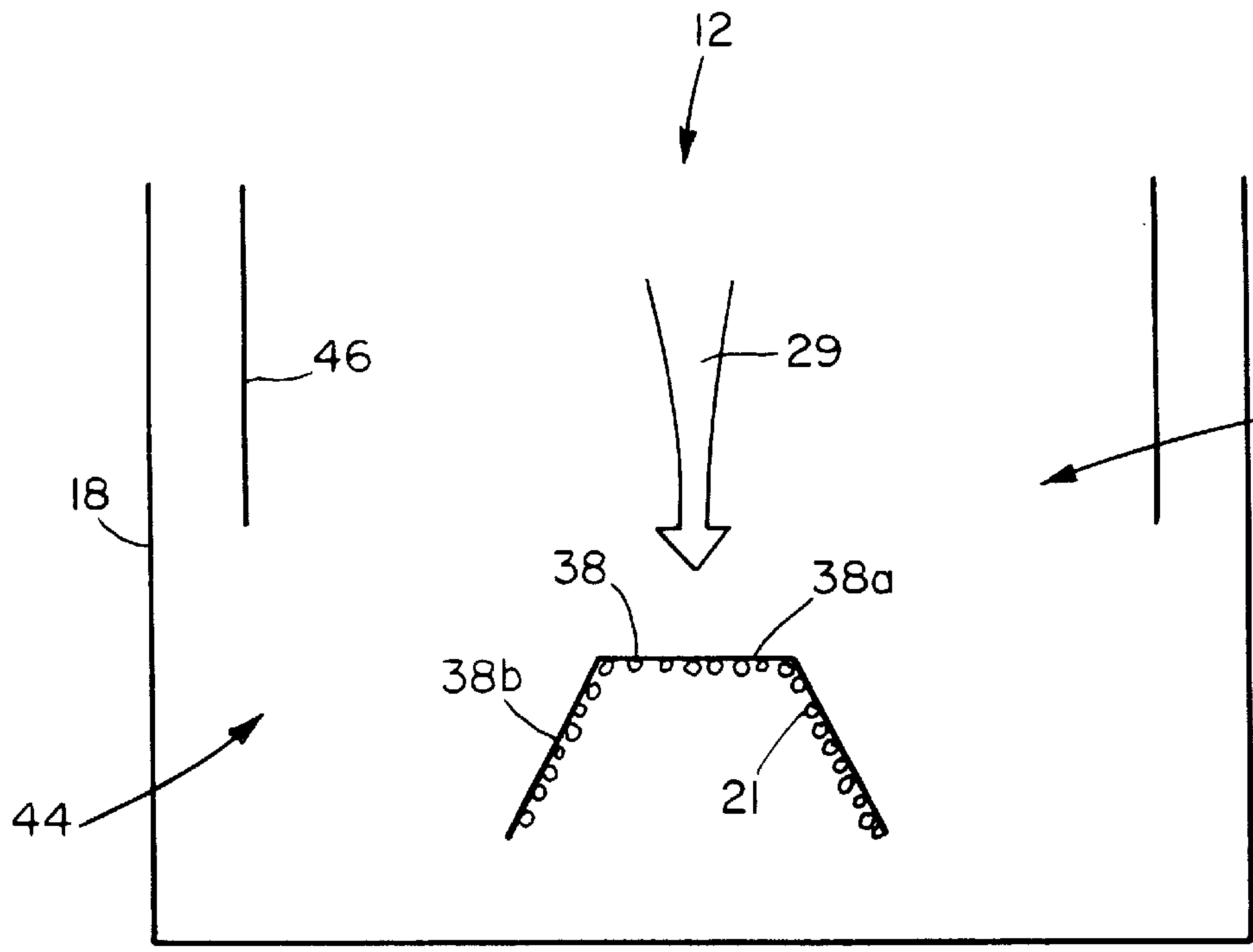
12
46
29
19
18
38
38a
38b
21
44

FIG. 6

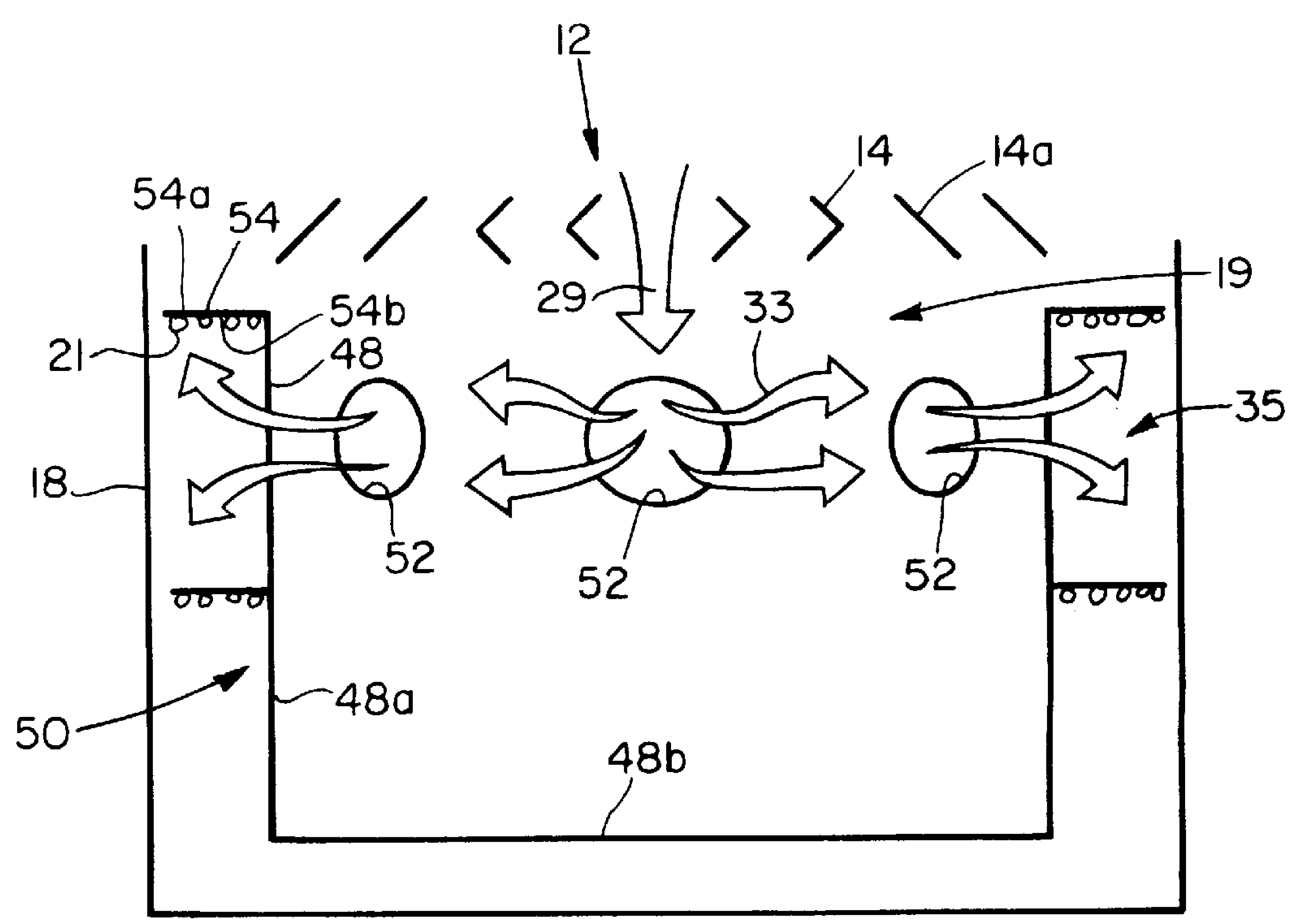
12
14
14a
54a
54
19
29
33
54b
21
48
35
18
52
52
52
50
48a
48b

FIG. 7

HIGH CAPACITY CRYOPUMP

BACKGROUND OF THE INVENTION

Cryopumps are typically cooled by either open or closed cryogenic cycles and generally follow the same design concept. A low temperature second stage primary cryopanel array, usually operating in the range of 4 to 25 K is the primary pumping surface. This surface is centrally located within a higher temperature housing, usually operated in the temperature range of 60 to 140 K, which provides radiation shielding to the lower temperature primary cryopanel array. The radiation shield is generally closed except at a first stage frontal array positioned between the primary cryopanel array and the process chamber to be evacuated. This higher temperature frontal array serves as a pumping site for higher boiling point gases such as water vapor.

In operation, high boiling point gases such as water vapor are condensed on the frontal array. Lower boiling point gases pass through that array into the interior of the radiation shield and condense on the primary cryopanel array. A surface coated with an adsorbent such as charcoal or a molecular sieve operating at or below the temperature of the primary cryopanel array may also be provided within the radiation shield to remove the very low boiling point gases such as hydrogen. To prevent overloading of the adsorbent, the adsorbent is generally provided on surfaces which are protected by the primary cryopanel array. By condensing or adsorbing gases onto the pumping surfaces, only a vacuum remains in the process chamber.

In cryopumps where the radiation shield fits closely about the primary cryopanel array, there is limited space between the radiation shield and the primary cryopanel array. In cryopumps of this design, there is a tendency for lower boiling point gases such as argon to condense heavily on the surfaces of the primary cryopanel array closest to the opening through which gases are cryopumped. When this occurs, frost from these condensing gases significantly narrows the gap between the radiation shield and the primary cryopanel array, limiting the ability of other gases to reach the condensing surfaces on the primary cryopanel array further away from the opening as well as the surfaces coated with adsorbent material. A significantly narrowed gap between the radiation shield and the primary cryopanel array greatly reduces the pumping speed of the cryopump.

SUMMARY OF THE INVENTION

The present invention is directed to a cryopump in which the pumping speed or capacity of the cryopump remains relatively high during operation. The cryopump includes a radiation shield, the shield having an interior surrounded by at least one wall. The radiation shield has an opening through which gases are cryopumped into the interior. A frontal cryopanel array is positioned near the opening for condensing high boiling point gases. The radiation shield and frontal cryopanel array are cooled to a first temperature. First primary cryopanel surfaces extending near the shield wall within its interior are cooled to a second temperature below the first temperature for condensing low boiling point gases such as argon near the wall while leaving a central gas flow pathway from the opening past the first primary cryopanel surfaces. Second primary cryopanel surfaces cooled to about the second temperature are positioned within the interior of the radiation shield and include adsorbent for adsorbing very low boiling point gases such as hydrogen. The first primary cryopanel surfaces limit the amount of low boiling point gases condensing on the second primary cryopanel surfaces while at the same time leaving open the central gas flow pathway to the second primary cryopanel surfaces.

In preferred embodiments, the radiation shield, frontal cryopanel array, and the first and second primary cryopanel surfaces are enclosed within a vacuum vessel. The first and second cryopanel surfaces are conductively coupled together with the first primary cryopanel surfaces substantially surrounding the second primary cryopanel surfaces. The second primary cryopanel surfaces include panels which are angled away from the opening and include adsorbent on the lower surfaces of the panels facing away from the opening. The frontal cryopanel array and the radiation shield are preferably cooled to about 60 K to 140 K and the first and second primary cryopanel surfaces are preferably cooled to less than about 25 K.

In other preferred embodiments, the first primary cryopanel surfaces are formed from a cylindrically shaped panel. In some embodiments, the cylindrically shaped panel can be cup-shaped. Additionally, in some embodiments, the second primary cryopanel surfaces include a frusto-conical shaped panel while in other embodiments, the second primary cryopanel surfaces are annularly shaped panels secured to the cylindrically shaped panel.

By extending the first primary cryopanel surfaces near the wall within the interior of the vacuum vessel, a large central gas flow pathway is left open which allows gases to flow freely to the second primary cryopanel surfaces. In addition, by limiting the amount of low boiling point gases condensing on the second primary cryopanel surfaces, very low boiling point gases such as hydrogen have relatively unrestricted access to the adsorbent and can be more quickly adsorbed, thereby maintaining a high hydrogen pumping speed.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. **1** is a side-sectional view of the present invention cryopump.

FIG. **2** is a perspective sectional view of the present invention cryopump.

FIG. **3** is a perspective view of the primary cryopanel array of the present invention cryopump.

FIG. **4**. is a schematic drawing of another preferred primary cryopanel array.

FIG. **5** is a schematic drawing of still another preferred primary cryopanel array.

FIG. **6** is a schematic drawing of yet another preferred primary cryopanel array.

FIG. **7** is a schematic drawing of still another preferred primary cryopanel array.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIGS. **1–3**, cryopump **10** includes a vacuum vessel **11** having a flange **16** for mounting the vacuum vessel **11** in communication with a process chamber. An opening **12** to the vacuum vessel **11** extends through flange **16**, thereby allowing the gases from the process chamber to enter the interior **19** of vacuum vessel **11**. Typically, a gate valve is positioned between the flange **16** of cryopump **10** and the process chamber **11** for bringing the process chamber in and out of communication with vacuum vessel **11**. Cryopump **10** also includes a cryogenic refrigerator **13** which is mounted to vacuum vessel **11**. Refrigerator **13** has a first cold finger **15***a* and a second cold finger **17***a* extending into the interior of vacuum vessel **11**. The first cold finger **15***a* and the second cold finger **17***a* are thermally coupled to a first thermal strut **15** and a second thermal strut **17**, respectively. Thermal struts **15** and **17** provide right angled thermal coupling to cold fingers **15***a*/**17***a*. Thermal strut **15** is conductively coupled to a radiation shield **18** positioned within the interior **19** of vacuum vessel **11** as well as a first stage or frontal cryopanel array **14** which is mounted to radiation shield **18** near opening **12**. Thermal strut **17** is conductively coupled to a low temperature second stage or primary cryopanel array **26** having inner cryopanel surfaces **20** and outer cryopanel surfaces **24** which are conductively coupled together. The radiation shield **18** provides radiation shielding for the primary cryopanel array **26**.

Frontal cryopanel array **14** includes a series of angled baffles **14***a*. The inner cryopanel surfaces **20** are centrally located within vacuum vessel **11** and extend between and above the outer cryopanel surfaces **24**. The inner cryopanel surfaces **20** include a series of downwardly angled panels **20***a* having adsorbent material **21**, preferably charcoal, adhered on the lower surfaces. Outer cryopanel surfaces **24** extend outwardly towards radiation shield **18** and then extend upwardly along radiation shield **18** close to the inner surface thereof. This leaves a relatively large gap **31** between the inner cryopanel surfaces **20** and the outer cryopanel surfaces **24**. The gap **31** is about the same as the width W of the inner cryopanel surfaces **20** so that the distance between the outer cryopanel surfaces **24** is about 3 times the width W (3:1 ratio).

Cold finger **15***a* and thermal strut **15** cool radiation shield **18** and frontal cryopanel array **14** to the same temperature, typically between about 60 K to 140 K, with about 80 K being the most preferred. In addition, cold finger **17***a* and thermal strut **17** cool primary cryopanel array **26** preferably to a temperature between about 4 K to 25 K, with 14 K being the most preferred.

In operation, gases enter cryopump **10** from the process chamber through opening **12** and pass over frontal cryopanel array **14**. Higher boiling point gases such as water vapor condense and freeze on the baffles **14***a* of frontal cryopanel array **14**. Lower boiling point gases such as hydrogen and argon pass through frontal cryopanel array **14** and enter the interior **19** of vacuum vessel **11**. Some of the lower boiling point gases such as argon entering the interior **19** of vacuum vessel **11** condense as frost **22** on the outer cryopanel surfaces **24** of primary cryopanel array **26**. The condensed gases on the outer cryopanel surfaces **24** are restricted to regions near the radiation shield **18** and thus away from the inner cryopanel surfaces **20**. This leaves open a large central gas flow pathway **29** which does not become blocked or significantly narrowed by condensing gases so subsequent low boiling point gases can flow through frontal cryopanel array **14** directly to the inner cryopanel surfaces **20**. The majority of the low boiling point gases condensed on the inner cryopanel surfaces **20** are located on the top portion thereof. Since the inner cryopanel surfaces **20** extend above the outer cryopanel surfaces **24**, the gases condensed as frost **22** on the top portion of the inner cryopanel surfaces **20** are substantially above the frost **22** on the outer cryopanel surfaces **24**, thereby preventing substantial narrowing of gap **31**. Consequently, the flow rate of gases towards outer cryopanel surfaces **24** and inner cryopanel surfaces **20** does not become significantly reduced during operation so that the pumping speed of low and very low boiling point gases remains relatively high.

In addition, the outer cryopanel surfaces **24** significantly limits the amount of low boiling point gases such as argon condensing on the inner cryopanel surfaces **20**. As a result, the low boiling point gases which condense as frost **22** on the panels **20***a* of the inner cryopanel surfaces **20** are at levels low enough not to significantly impede flow to the adsorbent **21** on the lower surfaces of panels **20***a*, thereby maintaining a high hydrogen pumping speed.

Consequently, the primary cryopanel array **26** provides a large open gas flow pathway **29** to the inner **20** and outer **24** cryopanel surfaces while keeping the adsorbent **21** on the lower surfaces of panels **20***a* relatively clear so that the pumping speed of low boiling point gases such as argon as well as very low boiling point gases such as hydrogen remains high.

FIG. **3** depicts primary cryopanel array **26** in further detail. The frame of primary cryopanel array **26** has two halves formed from sheet metal which are each bent to form a bottom wall **24***a*, an upright wall **27** extending vertically upward at a right angle from bottom wall **24***a*, and an outwardly and upwardly extending outer cryopanel surface **24**. Outer cryopanel surface **24** angles upwardly from bottom wall **24** and away from upright wall **27** before terminating in a section that is parallel to wall **27**. The two halves are joined together by fastening the two upright walls **27** together with fasteners **28** such as rivets or bolts which also serve to mount angled panels **20***a* to the exposed sides of the joined upright walls **27**. In the embodiment shown in FIG. **3**, there are three angled panels on each exposed side of the upright walls **27**. A series of holes **23** are formed in the bottom walls **24***a* for mounting primary cryopanel array **26** to thermal strut **17**. The adsorbent **21** adhered to the bottom surfaces of panels **20***a* is preferably charcoal adhered with epoxy but alternatively can be a molecular sieve. Cryopanel **26** is preferably formed from sheets of conductive metal 0.030 inch thick such as copper but can be made of other suitable materials such as aluminum. In addition, cryopanel **26** can be soldered or welded together instead of being fastened together with fasteners **28**.

FIGS. **4**–**7** are schematic illustrations of further embodiments of the invention. FIG. **4** depicts another preferred primary cryopanel array arrangement. Primary cryopanel array **32** differs from primary cryopanel array **26** in that cryopanel array **32** is generally circular in shape. Cryopanel array **32** includes a cup-shaped outer panel **34** and an inner frusto-conical shaped panel unit **25** centrally positioned within outer panel **34**. Outer panel **34** has an outer cylindrical wall **34***a* and a flat bottom wall **34***b*. Inner panel unit **25** includes an upper panel portion **36** and a lower panel portion **38**. Upper panel portion **36** has an angled side wall **36***b* and a flat upper wall **36***a*. Lower panel portion **38** is positioned within upper panel portion **36** with a gap therebetween and also has an angled side wall **38***b* and a flat upper wall **38***a*. Adsorbent **21** is adhered to the interior surface of lower panel portion **38**. The outer panel **34** and lower panel portion **38** are both cooled by cold finger **17***a* and thermal strut **17** preferably to a temperature of about 14 K to 20 K while upper panel portion **36** is cooled by cold finger **15***a* and thermal strut **15** preferably to a temperature of about 80 K. Lower boiling point gases such as argon condense on the walls **34***a* of outer panel **34** leaving open a large central gas flow pathway **29** to inner panel unit **25**. As a result, very low boiling point gases such as hydrogen have relatively unobstructed access to the adsorbent **21** within inner panel unit **25** for adsorption. Upper panel portion **36** shields and prevents overloading of the adsorbent **21**.

Referring to FIG. **5**, primary cryopanel array **40** is another preferred primary cryopanel array which differs from primary cryopanel array **32** in that a series of annular downwardly angled panels **42** are mounted to the interior surface of outer panel **34**. Both panels **34** and **42** are cooled by cold finger **17***a* and thermal strut **17** preferably to a temperature of about 14 K to 20 K. The outer panel **34** and the upper surfaces **42***a* of panels **42** condense low boiling point gases such as argon thereon while the lower surfaces **42***b* of panels **42** include adsorbent **21** for adsorbing very low boiling point gases such as hydrogen. It can be seen in FIG. **5** that a large central gas flow pathway **29** remains open as gases are trapped by primary cryopanel array **40**.

Referring to FIG. **6**, primary cryopanel array **44** is another preferred primary cryopanel array which differs from primary cryopanel array **32** in that outer panel **34** is replaced by an optically open cylindrical outer panel **46** positioned above a lower panel portion **38**. This allows a large amount of low boiling point gases such as argon to condense on outer panel **46** before reaching lower panel portion **38**. Both outer panel **46** and lower panel portion **38** are cooled by cold finger **17***a* and thermal strut **17** preferably to a temperature of about 14 K to 20 K. Since outer panel **46** is positioned close to radiation shield **18**, a large central gas flow pathway **29** remains open, thereby allowing very low boiling point gases such as hydrogen relatively unobstructed access to the adsorbent **21** located on the inner surface of lower panel portion **38**.

Referring to FIG. **7**, primary cryopanel array **50** is another preferred primary cryopanel array which differs from primary cryopanel array **40** in that a series of annular panels **54** are mounted to the exterior surface of a cup-shaped cylindrical panel **48**. Panel **48** includes a cylindrical side wall **48***a* extending upwardly from a bottom wall **48***b*. A series of openings **52** through wall **48***a* extend around the perimeter of panel **48**. Panel **48** is spaced a sufficient distance inwardly from radiation shield **18** to provide room for panels **54**. Panels **54** are preferably perpendicular to the wall **48***a* of panel **48** but alternatively, can be angled downwardly. Panels **48** and **54** are cooled by cold finger **17***a* and thermal strut **17** preferably to a temperature of about 14 K to 20 K. Panels **54** include upper surfaces **54***a* for condensing low boiling point gases such as argon thereon and lower surfaces **54***b* having adsorbent **21** for adsorbing very low boiling point gases such as hydrogen. The openings **52** allow gases flowing along the central gas flow pathway **29** to flow outwardly through openings **52** into the annular gap **35** between panel **48** and radiation shield **18** as shown by arrows **33** to become trapped on panels **54**.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

For example, although vacuum vessel **11** and primary cryopanel array **26** have been shown and described to have generally rectangular outer perimeters, alternatively, other suitable perimeter shapes can be employed such as circular or oval, etc. In addition, although primary cryopanel arrays **32**, **40**, **44** and **50** have been described to be generally circular about the perimeter, alternatively, the perimeter can be rectangular or be of other suitable shapes. Furthermore, the arrays do not have to be within vacuum vessel **11** but can be placed directly within the volume to be evacuated. Although terms such as upper, lower, side, top, vertical, upright, bottom, etc. have been used in describing the present invention, such terms describe the location of components relative to each other and are not meant to limit the present invention to a particular orientation.

What is claimed is:

1. A cryopump comprising:

a radiation shield having an interior surrounded by at least one wall, the radiation shield having an opening through which gases are cryopumped into the interior;

a frontal cryopanel array positioned near the opening for condensing high boiling point gases, the radiation shield and frontal cryopanel array being cooled to a first temperature;

first primary cryopanel surfaces extending near the wall within the interior of the radiation shield and cooled to a second temperature below the first temperature for condensing low boiling point gases near the wall of the radiation shield while leaving a central gas flow pathway from the opening past the first primary cryopanel surfaces; and

second primary cryopanel surfaces positioned within the interior of the radiation shield and cooled to about the second temperature including adsorbent for adsorbing very low boiling point gases, the first primary cryopanel surfaces limiting the amount of low boiling point gases condensing on the second primary cryopanel surfaces while leaving open the central gas flow pathway to the second primary cryopanel surfaces.

2. The cryopump of claim **1** further comprising a vacuum vessel enclosing the radiation shield, frontal cryopanel array, and the first and second primary cryopanel surfaces.

3. The cryopump of claim **2** in which the first primary cryopanel surfaces substantially surround the second primary cryopanel surfaces.

4. The cryopump of claim **3** in which the second primary cryopanel surfaces includes panels which are angled away from the opening.

5. The cryopump of claim **4** in which the frontal cryopanel array and the radiation shield are cooled to about 60 K to 140 K, and the first and second primary cryopanel surfaces are cooled to about 25 K or less.

6. The cryopump of claim **4** in which the first and second primary cryopanel surfaces are conductively coupled together.

7. The cryopump of claim **1** in which the adsorbent faces away from the opening of the vacuum vessel.

8. The cryopump of claim **1** in which the first primary cryopanel surfaces are formed from a cylindrically shaped panel.

9. The cryopump of claim **8** in which the cylindrically panel is cup-shaped.

10. The cryopump of claim **9** in which the second primary cryopanel surfaces are formed from annularly shaped panels secured to the cylindrically shaped panel.

11. The cryopump of claim **8** in which the second primary cryopanel surfaces include a frusto-conical shaped panel.

12. A cryopanel array for use in a cryopump having a radiation shield with an interior surrounded by a wall, the radiation shield having an opening through which gases are cryopumped, a frontal cryopanel array positioned near the opening for condensing high boiling point gases, the radiation shield and frontal cryopanel array being cooled to a first temperature, the cryopanel array comprising:

first primary cryopanel surfaces for extending near the wall within the interior of the radiation shield and for cooling to a second temperature below the first temperature for condensing low boiling point gases near the wall while leaving a central gas flow pathway past the first primary cryopanel surfaces; and

second primary cryopanel surfaces for positioning within the interior of the radiation shield and for cooling to about the second temperature including adsorbent for adsorbing very low boiling point gases, the first primary cryopanel surfaces for limiting the amount of low boiling point gases condensing on the second primary cryopanel surfaces while leaving open the central gas flow pathway to the second primary cryopanel surfaces.

13. The cryopump of claim **12** in which the adsorbent is positioned to face away from the opening of the vacuum vessel.

14. The cryopump of claim **12** in which the first primary cryopanel surfaces substantially surround the second primary cryopanel surfaces.

15. The cryopump of claim **14** in which the second primary cryopanel surfaces includes panels which are angled away from the opening.

16. The cryopump of claim **12** in which the first and second primary cryopanel surfaces are cooled to about 25 K or less.

17. The cryopump of claim **12** in which the first and second cryopanel surfaces are conductively coupled together.

18. The cryopump of claim **12** in which the first primary cryopanel surfaces are formed from a cylindrically shaped panel.

19. The cryopump of claim **18** in which the cylindrically shaped panel is cup-shaped.

20. The cryopump of claim **19** in which the second primary cryopanel surfaces are formed from annularly shaped panels secured to the cylindrically shaped panel.

21. The cryopump of claim **18** in which the second primary cryopanel surfaces include a frusto-conical shaped panel.

22. A cryopump comprising:

a radiation shield having an interior surrounded by at least one wall, the radiation shield being cooled to a first temperature and having an opening through which gases are cryopumped into the interior;

first primary cryopanel surfaces extending near the wall within the interior of the radiation shield and cooled to a second temperature below the first temperature for condensing low boiling point gases near the wall of the radiation shield while leaving a central gas flow pathway from the opening past the first primary cryopanel surfaces; and

second primary cryopanel surfaces positioned within the interior of the radiation shield and cooled to about the second temperature including adsorbent for adsorbing very low boiling point gases, the first primary cryopanel surfaces limiting the amount of low boiling point gases condensing on the second primary cryopanel surfaces while leaving open the central gas flow pathway to the second primary cryopanel surfaces.

23. A method of cryopumping gases with a cryopump, the cryopump including a radiation shield having an interior surrounded by at least one wall, the radiation shield having an opening through which gases are cryopumped, the method comprising the steps of:

condensing high boiling point gases on a frontal cryopanel array positioned near the opening, the radiation shield and frontal cryopanel array being cooled to a first temperature;

condensing low boiling point gases on first primary cryopanel surfaces extending near the wall within the interior of the radiation shield while leaving a central gas flow pathway from the opening past the first primary cryopanel surfaces, the first primary cryopanel surfaces being cooled to a second temperature below the first temperature; and

adsorbing very low boiling point gases with adsorbent located on second primary cryopanel surfaces, the second primary cryopanel surfaces being cooled to about the second temperature, the first cryopanel surfaces limiting the amount of low boiling point gases condensing on the second primary cryopanel surfaces while leaving open the central gas flow pathway to the second primary cryopanel surfaces.

24. The method of claim **23** further comprising the step of enclosing the radiation shield, frontal cryopanel array, and the first and second primary cryopanel surfaces within a vacuum vessel.

25. The method of claim **24** further comprising the step substantially surrounding the second primary cryopanel surfaces with the first primary cryopanel surfaces.

26. The method of claim **24** further comprising the steps of:

cooling the frontal cryopanel array and the radiation shield to about 60 K to 140 K; and

cooling the first and second primary cryopanel surfaces to between about 25 K or less.

27. The method of claim **23** further comprising the step of conductively coupling the first and second primary cryopanel surfaces together.

28. A method of cryopumping gases with a cryopump, the cryopump including a radiation shield having an interior surrounded by at least one wall, the radiation shield being cooled to a first temperature and having an opening through which gases are cryopumped, the method comprising the steps of:

condensing low boiling point gases on first primary cryopanel surfaces extending near the wall within the interior of the radiation shield while leaving a central gas flow pathway from the opening past the first primary cryopanel surfaces, the first primary cryopanel surfaces being cooled to a second temperature below the first temperature; and

adsorbing very low boiling point gases with adsorbent located on second primary cryopanel surfaces, the second primary cryopanel surfaces being cooled to about the second temperature, the first cryopanel surfaces limiting the amount of low boiling point gases condensing on the second primary cryopanel surfaces while leaving open the central gas flow pathway to the second primary cryopanel surfaces.

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